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Cold Regions Research and Engineering Laboratory

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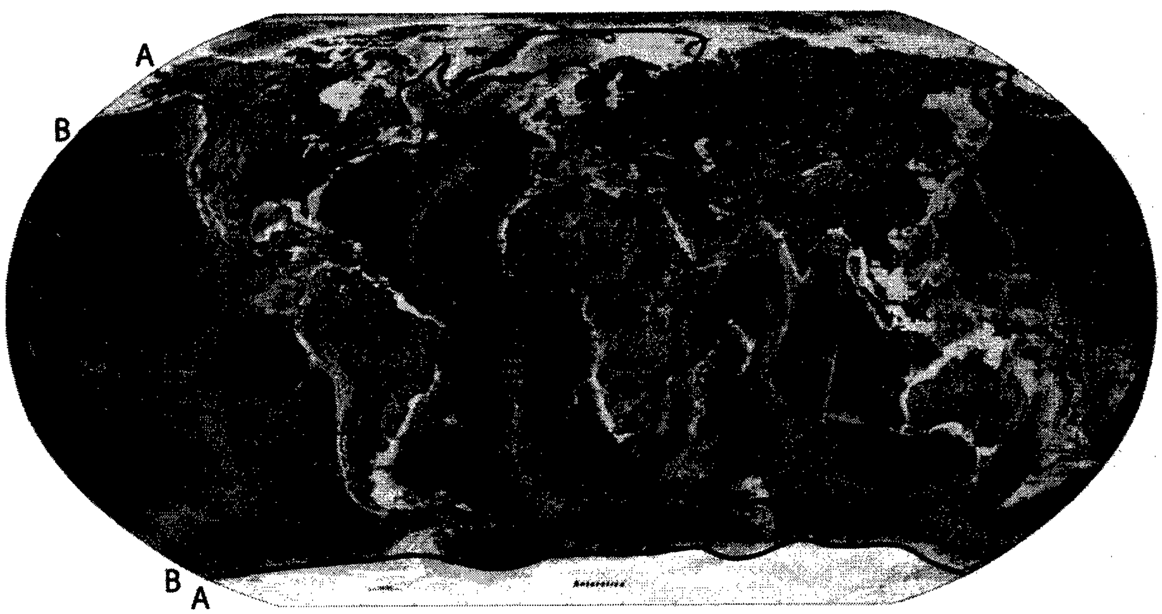
Cold Regions Issues for Off-Road Autonomous Vehicles

Deborah Diemand and James H. Lever

April 2004



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Front cover: Regions of the world considered severely cold (A) and moderately cold (B). Lines are based on Bates and Bilello (1966). World map from DI Cartography Center (1999).

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ABSTRACT

About half of Earth's land mass experiences mean temperatures below 0°C during the coldest month. Attendant conditions pose major challenges to the operation of off-road autonomous vehicles. Low-temperature effects on lubricants, materials, and batteries can impair a robot's ability to operate at all. Cold starting will be a serious problem if missions require long periods of engine shutdown. Deep snow can easily immobilize vehicles on terrain that would otherwise pose no problems. Blowing snow and icing can also degrade the performance of sensors needed for navigation and target detection. Winter operation of passenger vehicles and construction equipment provides guidance to surmount cold-regions effects on robotic vehicles. This report identifies problems likely to be encountered, simple preventative measures, and references for additional information. Conditions are sufficiently demanding that off-road autonomous vehicles must be designed for and tested in cold regions if they are expected to operate there successfully.

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PREFACE

This report was prepared by Deborah Diemand, Physical Scientist, and Dr. James H. Lever, Mechanical Engineer, Applied and Military Research Branch, U.S. Army Engineer Research and Development Center (ERDC), Cold Regions Research and Engineering Laboratory (CRREL), Hanover, New Hampshire.

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The Commander of the Engineer Research and Development Center is Colonel James R. Rowan, EN. The Director is Dr. James R. Houston.

Cold Regions Issues for Off-Road Autonomous Vehicles

DEBORAH DIEMAND AND JAMES H. LEVER

1 INTRODUCTION

This report briefly describes cold-regions issues of concern for off-road autonomous vehicles (i.e., robots). It identifies the most serious problems likely to be encountered, simple preventative measures, and references for additional information.

Essentially, the difficulties of maintaining and operating manned vehicles in cold regions are exacerbated for unmanned vehicles. Operability issues such as cold starting may be serious if missions require long periods of engine shutdown for stealth or energy conservation. Vehicles can easily become immobilized in deep snow covering terrain that would otherwise pose no problems. Blowing snow and icing can also degrade the performance of sensors needed for autonomous navigation and target/intruder detection.

Experience with winter operation of automobiles, trucks, and construction equipment provides a wealth of guidance to avoid many problems. However, many issues unique to off-road autonomous mobility, navigation, and control are compounded by winter conditions and will require considerable effort to surmount. Conditions are sufficiently demanding that ground robots must be designed for and tested in cold regions if they are expected to operate there successfully.

2 COLD REGIONS

About one-quarter of Earth's land mass (all of Siberia, Greenland, and Antarctica; most of Canada and Alaska; and parts of China and northern Europe) may be termed "severely cold" (Bates and Billello 1966, Freitag and McFadden 1997). Mean annual air temperatures are below 0°C, maximum snow depths exceed 60 cm, and lakes and rivers are ice covered for more than 180 days. Another one-quarter (including most of the United States and Eurasia) may be termed "moderately cold," where mean air temperatures during the coldest month are below 0°C. Figure 1 shows the extent of cold regions so defined. While these definitions are useful, vehicles respond to actual conditions. It is important to note that daily minimum temperatures can be 20°C lower than monthly means, and snowdrifts can be several times deeper than the average snow cover.

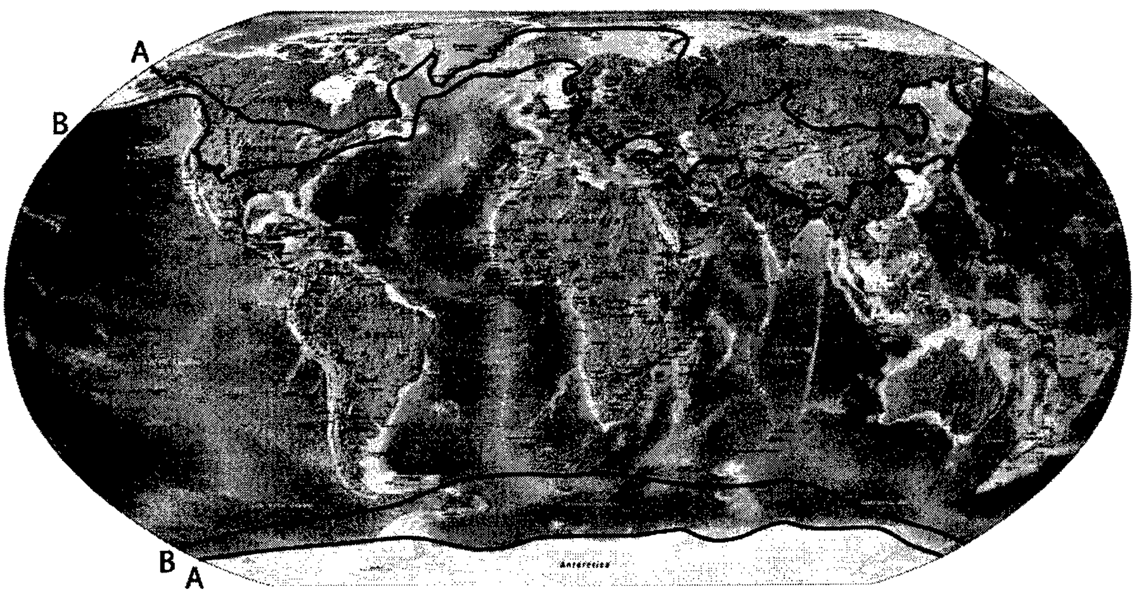


Figure 1. Regions of the world considered severely cold (A) and moderately cold (B). Lines are based on Bates and Bilello (1966). World map from DI Cartography Center (1999).

There are few areas in the world where extremely low temperatures are commonplace. Not surprisingly, these areas are not heavily populated. Sustained temperatures below –40°C are commonly present during winter months in the polar regions, on the Greenland ice cap, at extremely high elevations, in central Alaska, parts of northern Canada, and north central Asia. However, vehicles

begin to experience problems whenever temperatures drop below freezing; below –20°C problems with lubricants, batteries, and materials can be significant. Also, regardless of temperature, the presence of snow cover, ice, frozen or thawing ground, or freezing precipitation frequently creates problems for vehicle travel.

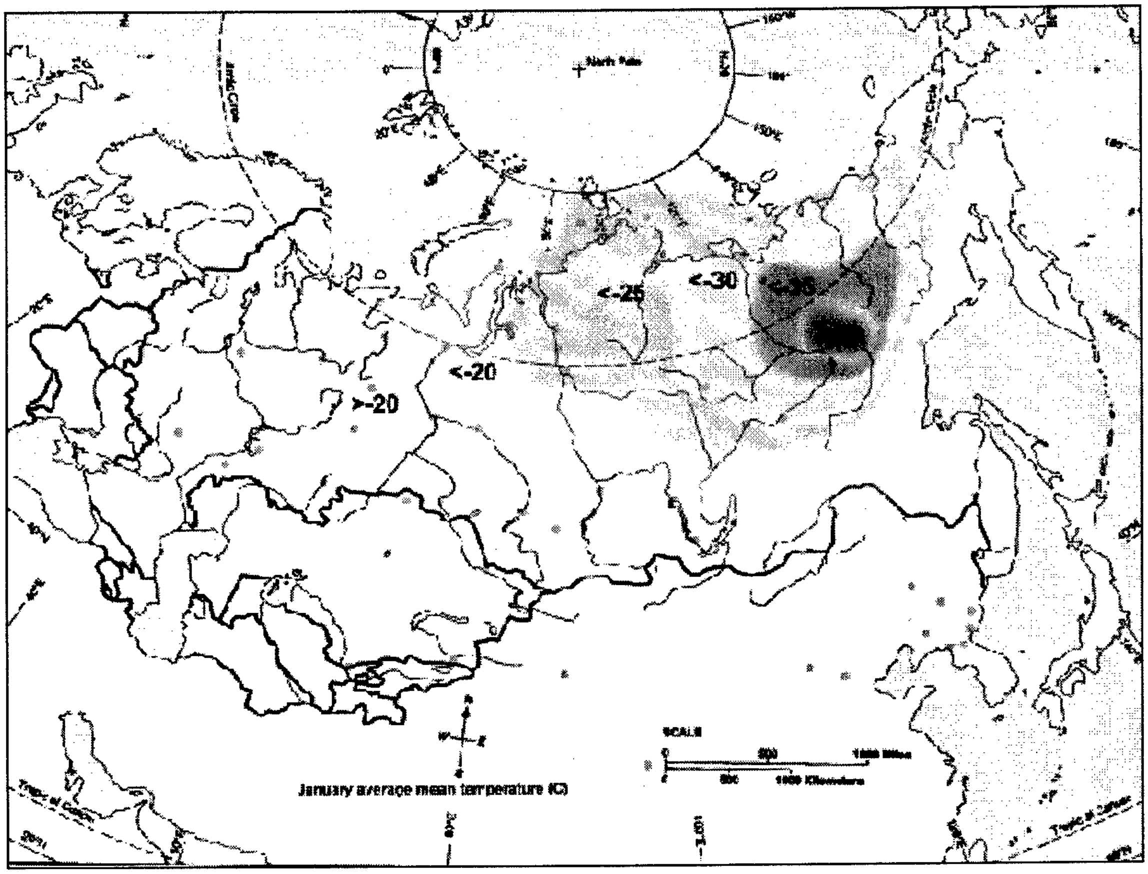


Figure 2. Areas of Eurasia where average mean monthly temperature is less than –20°C.

An example will serve to illustrate how climatic data may be used to define vehicle design temperatures for a region of interest. Figure 2 is a map of Eurasia showing average mean monthly temperatures for the month of January, which in most northern locations is the coldest month. Figure 3 shows the average daily minimum temperatures for the same time and region. The data used to construct these temperature distributions are from the National Climate Data Center (1996) and are listed in Appendix A. A more detailed data set for two sites is given in Appendix B. Curapca, Russia, is located in the coldest core shown on the maps, with an average mean daily temperature in January of less than –40°C.

Khanty–Mansiysk, Russia, is located at the western edge of the highlighted region, with an average mean daily temperature greater than –20°C. The two are roughly 1° of latitude apart and 140 m of elevation. This suggests that latitude and elevation alone are not useful guides for estimating temperatures that may be encountered.

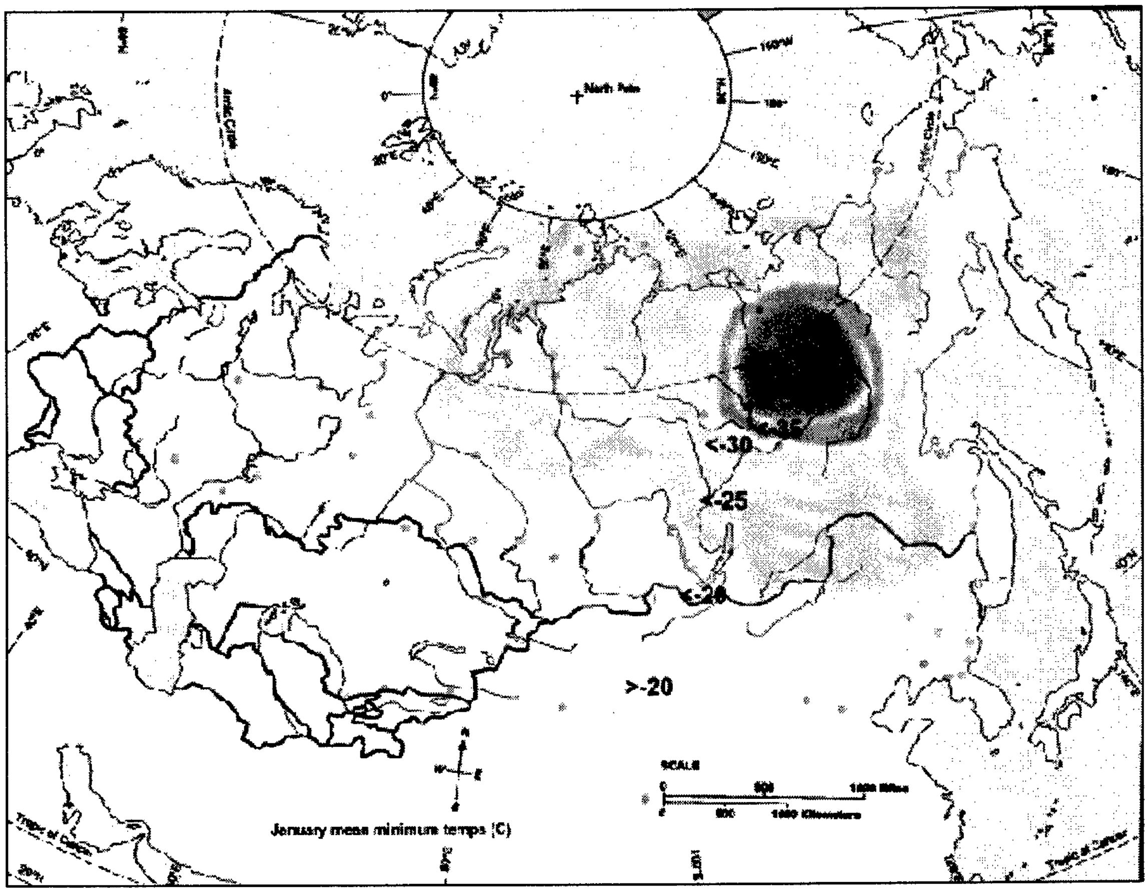
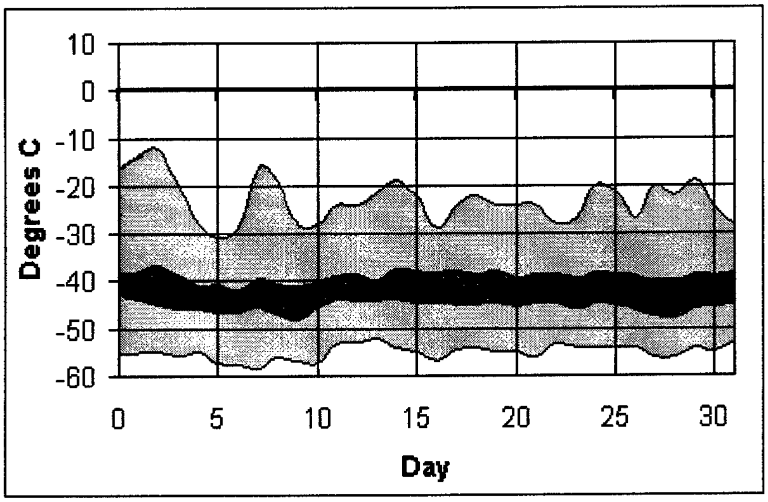


Figure 3. Areas of Eurasia where average minimum monthly temperature is less than –20°C.

In addition to monthly averages, the temperature extremes possible for an individual site are important. Figure 4 shows plots of the January daily average mean temperatures (bold line) for Curapca and Khanty–Mansiysk. The mean curve is bracketed by the daily average maximum and minimum temperatures (dark grey) and these are bracketed by the historical extremes (light grey). It is clear from these plots that while the mean January temperatures appear to be quite steady, possible excursions for the averages may prove catastrophic in

terms of vehicle operability. Standard deviations for January tell the same story (Appendix A). For example, Khanty–Mansiysk has a monthly average minimum temperature of –23°C with a standard deviation of about 10°C, so that temperatures below –30°C are common in January. Because daily minimum temperatures often occur overnight, vehicles in nighttime silent mode (engine off) may experience cold soaking that impedes start-up and smooth operation the next morning.



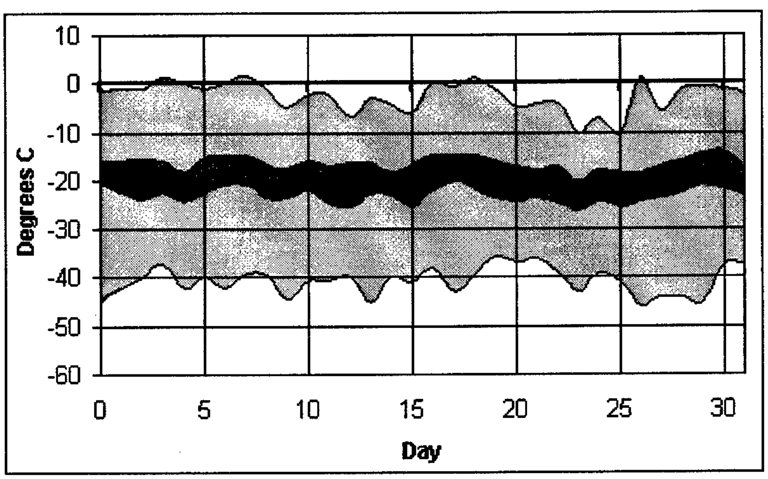


Figure 4. Plots of the January mean daily temperatures from Curapca (top) and Khanty–Mansiysk (bottom) as well as the average daily maxima and minima (dark grey) and historical extremes (light grey) for each day.

3 EQUIPMENT OPERABILITY PROBLEMS IN COLD REGIONS

Included here are brief descriptions of the nature of, and solutions for, problems commonly encountered in operating vehicles and construction equipment in cold regions. Robotic vehicles will encounter similar problems but may be expected to perform well without human intervention. Note that the coverage here is certainly not exhaustive. Diemand (1990; 1991a, b, c, d; 1992) and Freitag and McFadden (1997) provide much more detail and extensive references.

Temperature-Dependent Problems

Engine Oil

Lubricants represent the single most critical problem encountered by vehicles in cold regions (Diemand 1990). Engine oils must work effectively at extremes defined by ambient low temperatures and full-load high temperatures. Cold-starting problems and poor lubrication result if engine oil is too viscous at low temperatures. Prolonged idling at low temperatures can also cause excessive sludge formation from blow-by products, including water, gasses, and unburned fuel.

Oil performance may be characterized by several measures, including viscosity at temperature extremes (say, –30°C and 100°C), viscosity index (a high value indicates the oil is insensitive to temperature variations), and borderline pumpability temperature (a measure of the ability of the oil to circulate at low temperatures).

Several good quality, multigrade oils are available for use in cold regions, including Oil, Engine, Arctic (OEA), a 0W20 synthetic lubricant used by the military for ambient temperatures from 40°C to –50°C. In addition, all machinery in cold regions is equipped with engine heaters, and both block and pan heaters are highly recommended to minimize cold-starting problems (Diemand 1990). Frequent oil and filter changes are also recommended.

Other Lubricants

In general, the drivetrain will need to perform under the most extreme conditions, since it is continuously exposed to ambient temperatures. Again, the lubricant must have sufficient viscosity to protect the gears from high contact stresses at operating temperatures, yet flow well at low ambient temperatures to

permit start-up. Multigrade 75W90 synthetic gear oil is commonly used in cold regions (Diemand 1990). Even low-temperature lubricants will thicken at sufficiently low temperatures and, especially at start-up, abrupt accelerations may cause breakage or damage to gears and axles. Slow, gentle acceleration and operation is recommended until the drivetrain warms to operating temperature.

Arctic hydraulic and brake fluids are also available and advisable for low-temperature use (Diemand 1990). Water absorption, leakage, excessive pump water, and stiffening are the main concerns. Even with a suitable fluid, it is best to warm hydraulic systems at no load before subjecting them to full-load application.

Fuel

The heavier grades of diesel fuel are seldom used in cold regions because they tend to solidify at relatively high temperatures. For example, the cloud point of DL-2, the temperature at which the heavier components begin to crystallize, is about –12°C. That of JP-8, on the other hand, is lower than –60°C, making it a better choice for use in the extreme cold. However, even light fuels will ignite with greater difficulty as the temperature falls, and heating the fuel tank (or at least the fuel lines) should be considered.

Coolant

With a proper coolant/water ratio, the coolant will not freeze above about –40°C. In fact, even below this it will not damage the engine since it will freeze into a slurry rather than a solid block and will therefore not cause expansion damage as water would. However, if the engine is forced to start when the coolant is not fully fluid, the coolant will not circulate properly and engine damage could result from local overheating.

Low Temperature Operation

While low temperatures make starting an engine very difficult, they also may have an adverse affect on operation, and heat retention measures should be used. The optimum design of heat retention devices should enable the engine to reach an operating temperature range of 85–93°C under the worst possible conditions. In extremely cold temperatures an engine that has not been properly winterized may not reach this temperature, resulting in greatly increased numbers of failures and reduced fuel efficiency.

A few of the problems experienced by engines run at low operating temperatures are as follows: